# IER 537: Update on CERBERUS Experiment Execution & HEU Plate Characterization

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2024 NCSP Technical Program Review

LA-UR-24-20884

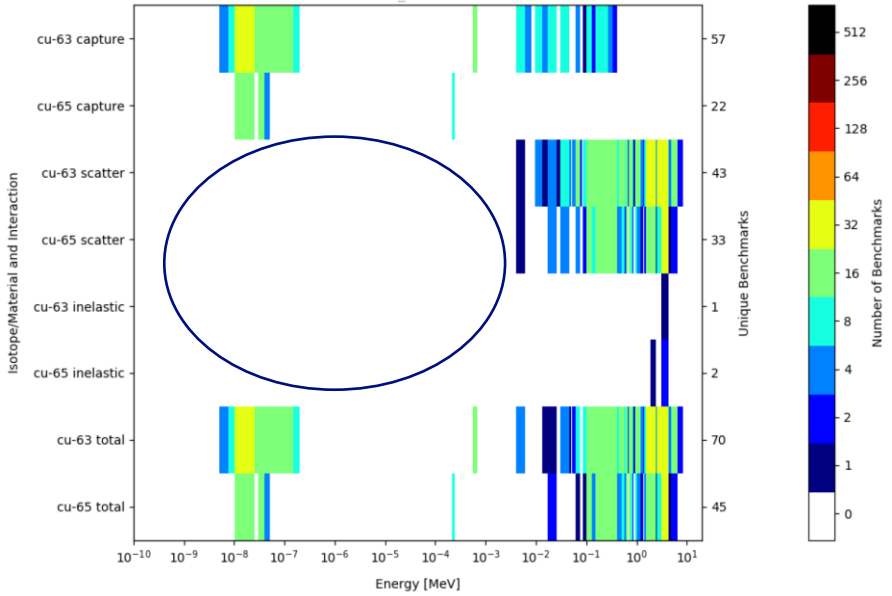
Cartoon from: goofygodscomics

# CERBERUS Completed Experiment Execution

# Overview of CERBERUS

**C**ritical **E**xperiment **R**eflected **B**y copp**E**r to bette**R** **U**nderstand **S**cattering **(CERBERUS)**

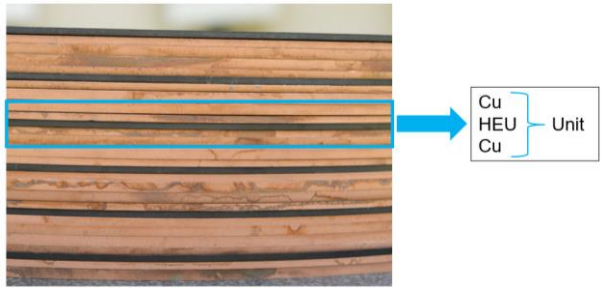
- Focus on the intermediate energy spectrum
- Help resolve uncertainties in the elastic and inelastic scattering cross sections of $^{63}Cu$ and $^{65}Cu$.




Credit to Nick Thompson for this graphic

# CERBERUS Configurations

- Core Materials:
  - HEU
  - Cu
- 3 critical configurations that vary in Cu thickness



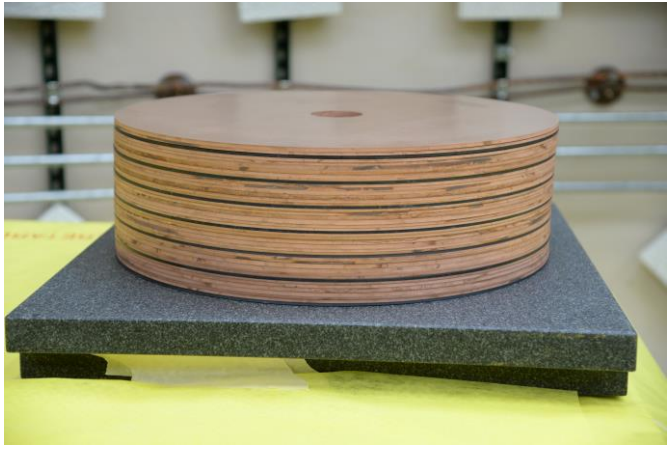

| Config. | Date | # of Units | HEU Mass [kg] | Reactivity [¢] |
|---|---|---|---|---|
| 3/16 | September 13, 2023 | 11 | 137.2 | 10.13 |
| 5/16* | August 10, 2023 | 12 | 149.7 | 29.28 |
| 7/16 | September 20, 2023 | 14 | 173.8 | 16.90 |

* Additional measurements performed: Rossi-α, leakage spectra, and foil irradiations

# Coordinate Measuring Machine (CMM) Stack Heights

- Reports highly consistent numbers
  - Average of four measurements
  - More on measuring procedure later
- Compare to individual measured heights to quantify the gaps


| Config. | Stack | Avg. Height (cm) | Std. Dev. (cm) | Expected Height (cm) | Total Gaps (cm) |
|---|---|---|---|---|---|
| 3/16 | Top | 6.40325 | 0.00952 | 6.31881 | 0.08444 |
| | Bottom (No Al) | 7.23675 | 0.00750 | 6.77886 | 0.45789 |
| 5/16 | Top | 10.71520 | 0.00426 | 10.60441 | 0.11079 |
| | Bottom | 10.81500 | 0.00474 | 10.58739 | 0.22761 |
| 7/16 | Top | 17.11200 | 0.01125 | 16.98201 | 0.12999 |
| | Bottom | 16.51250 | 0.00698 | 16.31246 | 0.20004 |



**Preliminary Analysis**

# Project Schedule

- Experiment execution time was 3 weeks
- CED-3B report completed in December 2023
- Planning to submit ICSBEP evaluation for 2025 TRG meeting
  - Evaluator(s): Kelsey Amundson & Zach Lemke (LANL)
  - Internal Reviewer: Theresa Cutler (LANL)
  - Independent Reviewer: Jacob Glesmann (LLNL)

| Task | FY2021 | | | | FY2022 | | | | FY2023 | | | | FY2024 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |
| CED-1 | | | | | | | | | | | | | | | | |
| CED-2 | | | | | | | | | | | | | | | | |
| CED-3A | | | | | | | | | | | | | | | | |
| CED-3B | | | | | | | | | | | | | | | | |

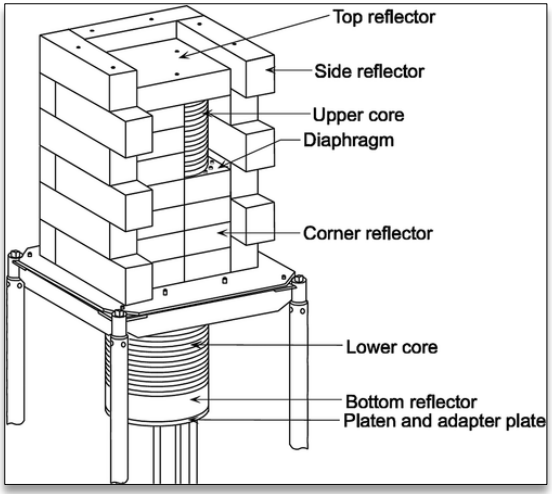
# Big Thanks to IER 537 CED Team!

- **Project Lead:** T. Cutler (LANL)
- **Experiment Lead:** K. Amundson (LANL)
- **NDAG Member:** M. Zerkle (NNL)
- **Methods Member:** J. McDonnell (ORNL)
- **Team Members:** J. Goda (LANL) & V. Sobes (UTK)
- **Advisors:** R. Little (LANL), T. Kawano (LANL), J. Hutchinson (LANL), N. Thompson (LANL), L. Leal (ORNL)

# CMM Characterization of HEU Pancake Plates

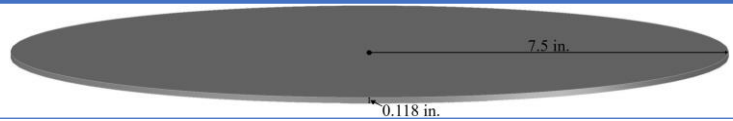
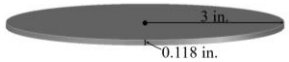
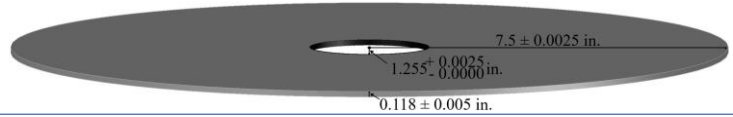
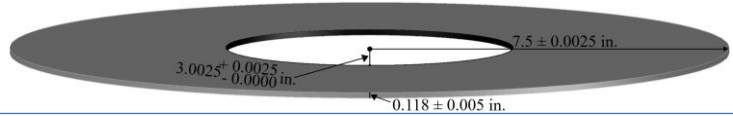
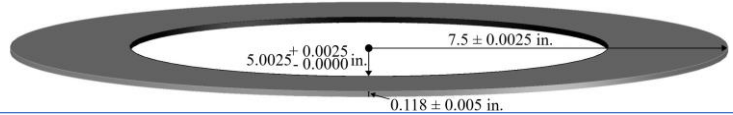
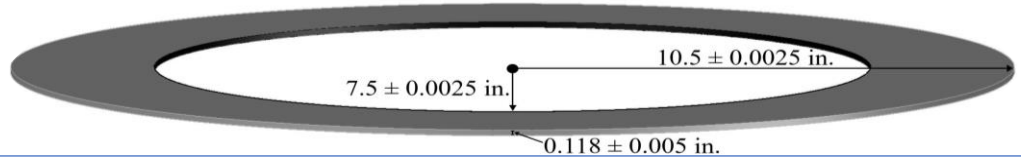
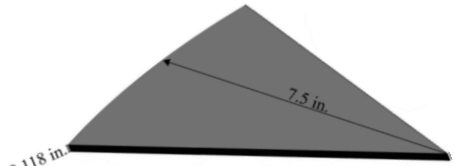
# HEU Pancake Plates

- There are 65 total HEU Pancake (Jemima) Plates
- Ordered in 2 sets
  - Set 1: Ordered by LANL in 1958
  - Set 2: Ordered by ORNL later
- Moved to NCERC in the early 2000's
- Used in numerous experiments from TA-18 to now
  - HEU-MET-FAST-072, HEU-MET-FAST-073, HEU-MET-FAST-102, HEU-MET-INTER-006, HEU-MET-INTER- 011, HEU-MET-MIXED-021, and IEU-MET-FAST- 025



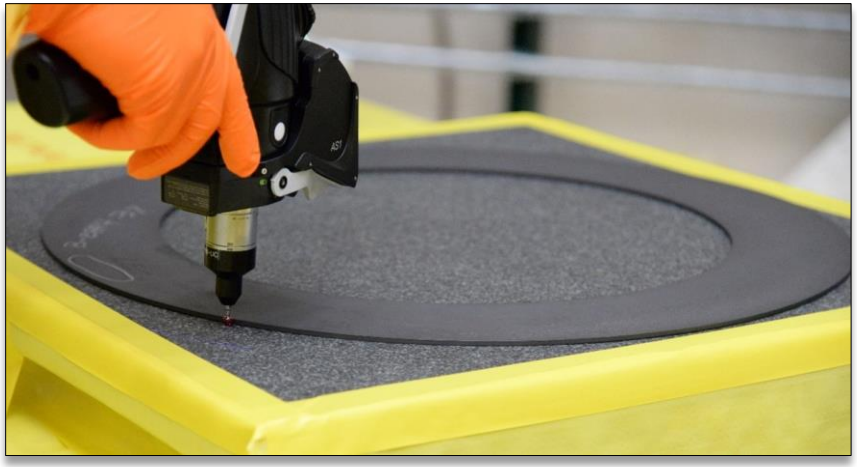

# Motivation

- Follow up to 2019 measurements
- The HEU plates have been utilized in numerous experiments
- Different combinations of mass, caliper measurements, and drawing dimensions have resulted in different densities
  - Large density ranges (17g/cm$^3$ to 19 g/cm$^3$)
  - Unrealistic densities (>19 g/cm$^3$)
- This work focuses on proposing a uniform method of defining the plates

| Plate Type | Plate Quantity | Approx. Mass (kg) | Plate Schematic |
|---|---|---|---|
| HEU 15/0 | 5 | 6.5 |   |
| HEU 6/0 | 1 | 1.1 |   |
| HEU 15/2.5 | 7 | 6.3 |   |
| HEU 15/6 | 7 | 5.5 |   |
| HEU 15/10 | 8 | 3.6 |   |
| HEU 21/15 | 31 | 6.1 |   |
| HEU Wedge | 6 | 1.1 |   |

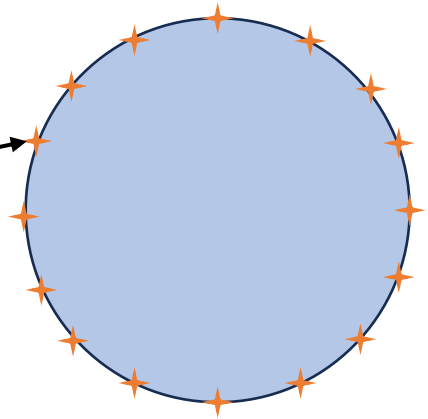
# Measurement Tools

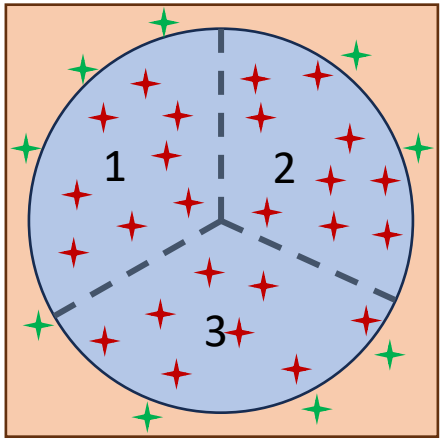
- 2019 Measurements
  - Mass: 16-kg Mettler Toledo scale (MS16001L)
  - Height: Brown & Sharp IP67 caliper
- 2023 Measurements
  - Mass: 16-kg Mettler Toledo scale (MS16001L)
  - Height: Brown & Sharp IP67 caliper
  - Height & Diameters: Hexagonal Absolute Arm V2P, 8525, 7-Axis CMM

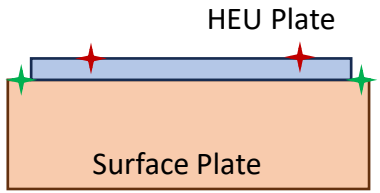


# CMM Measurement Procedure

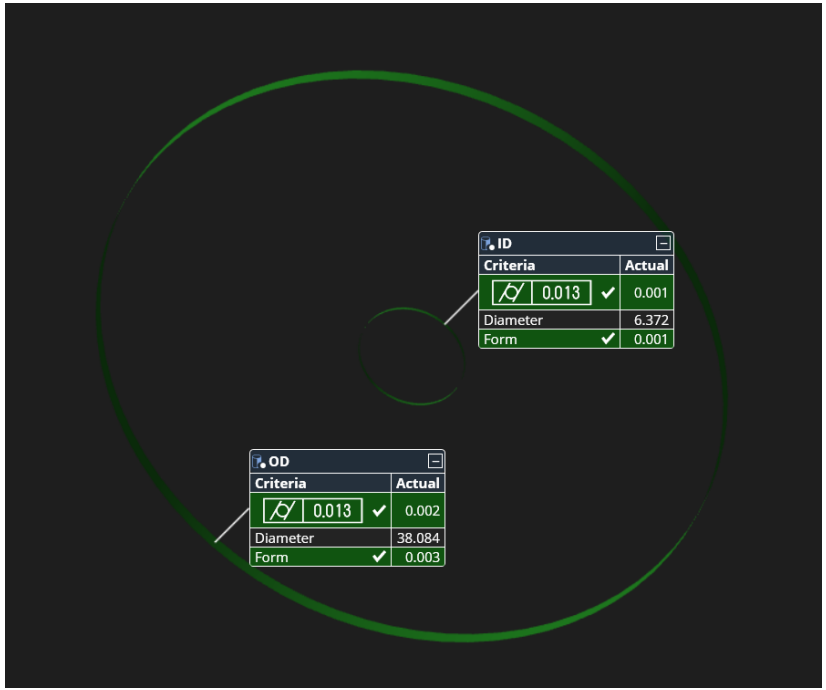
- Diameter(s):
  - Use probe to make 12 – 15 points along the diameter
  - Fit to cylinder
- Height:
  - Take ~8 points for each measurement
  - Measurements taken:
    - Average of the granite surface plate
    - Average of top of HEU plate
    - 3 sectional averages of top of HEU plate
    - Compute difference back to the surface plate

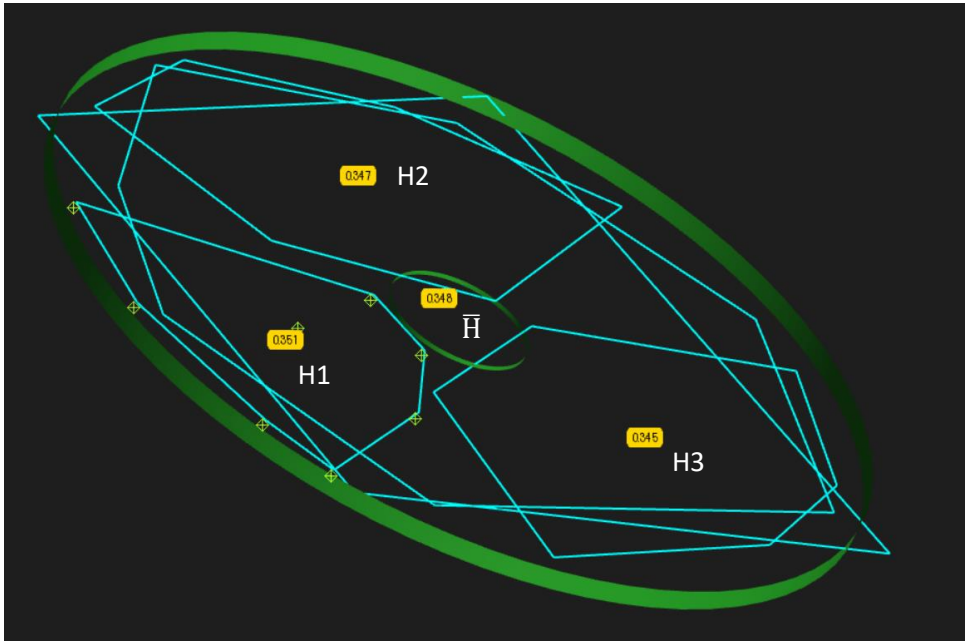




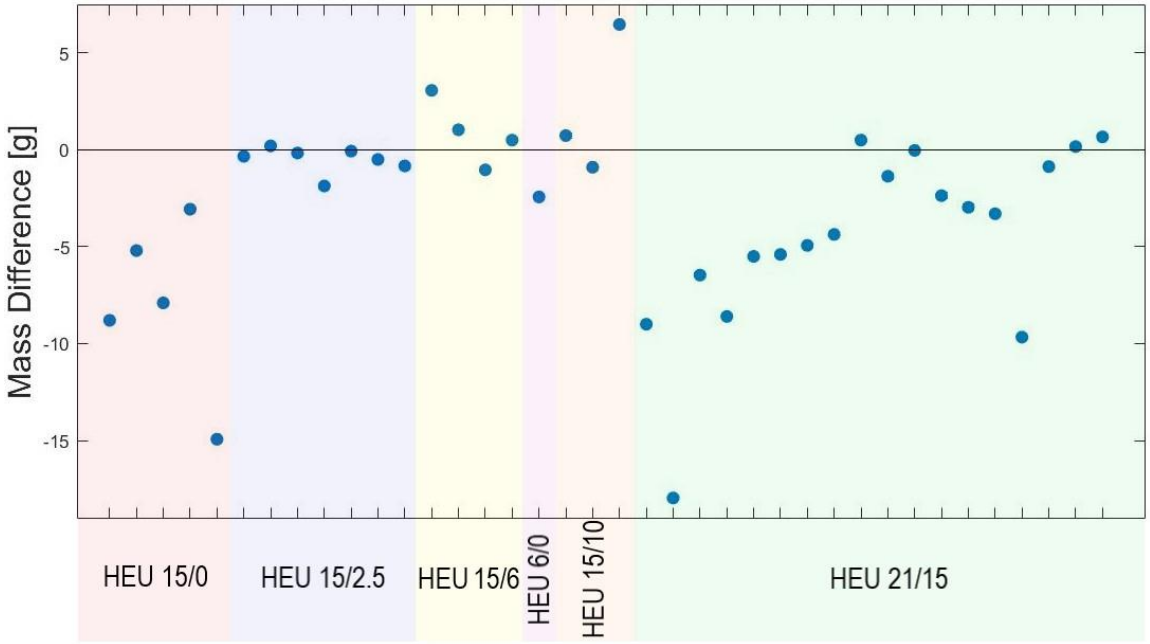
# CMM Measurements of Plate 10491



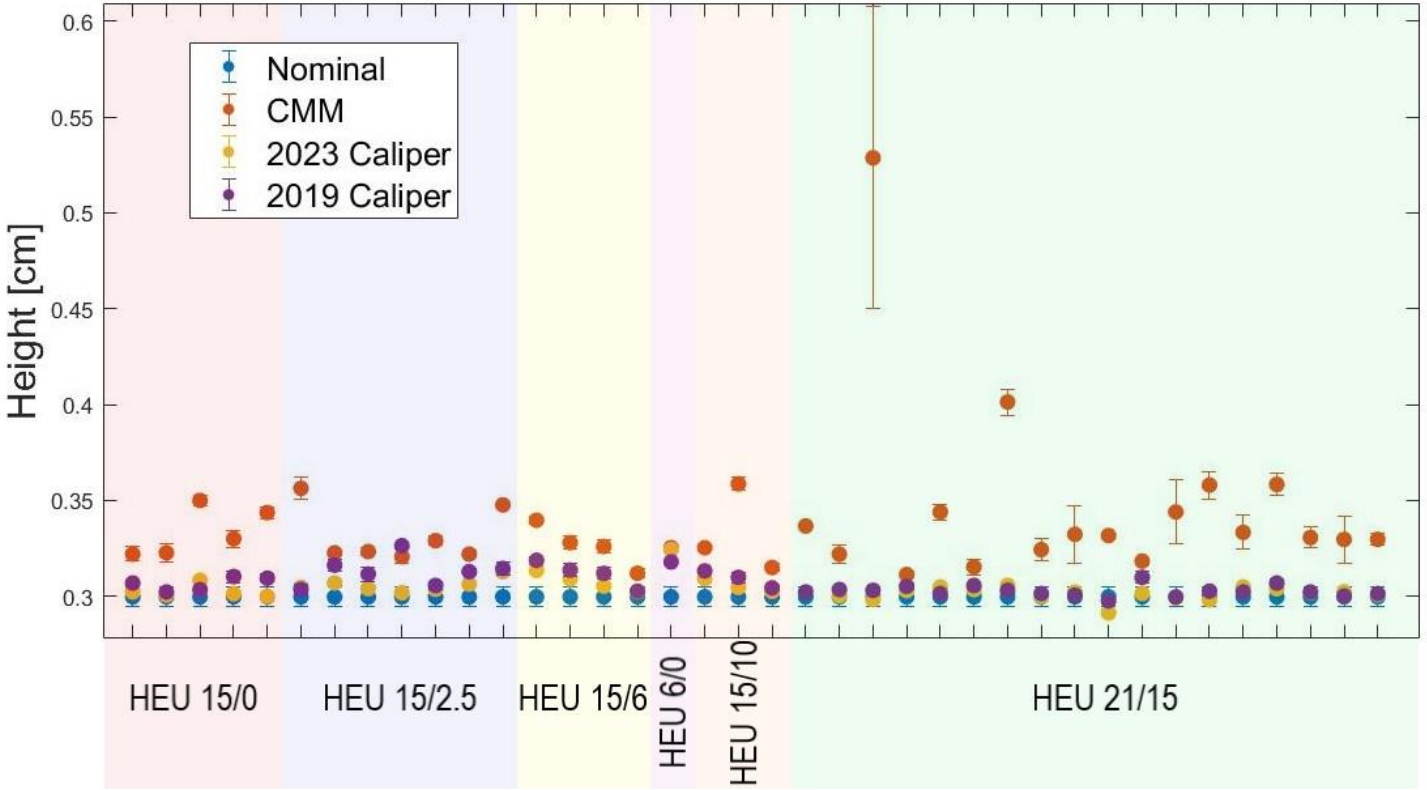



# Mass Difference Between 2019 & 2023

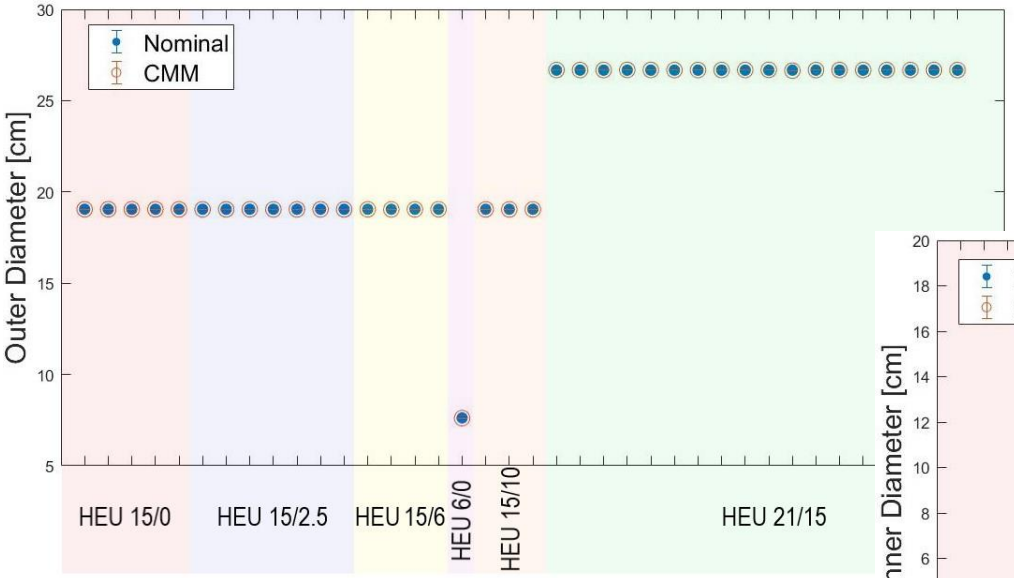
- Most mass differences are negative showing mass lost due to oxidation flaking
- 2019 masses were only measured once, so no statistical uncertainty is available

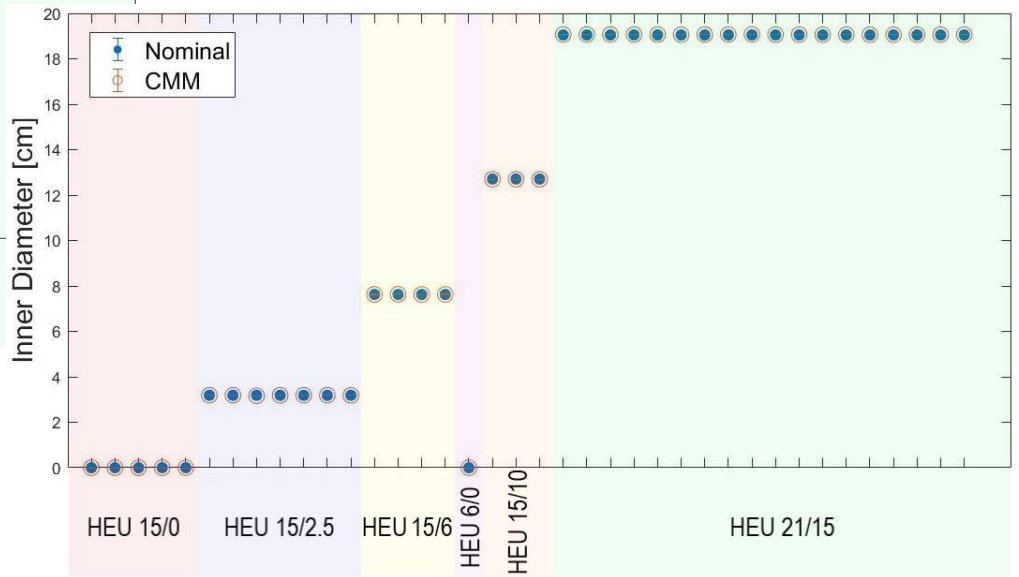


# CMM Height Measurements



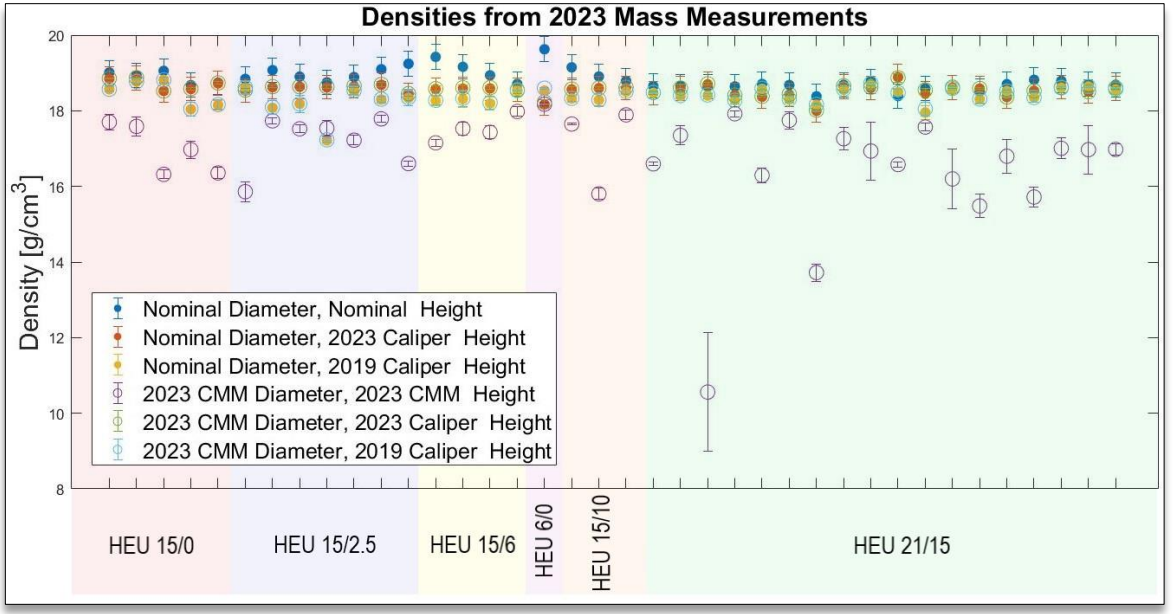
# CMM Diameter Measurements



# Density Calculations

- Densities are expected to be similar across the plates
  - Manufactured in the same way
  - Similar compositions
- CMM height measurements cause large spread in density



# Statistical Analysis of Density Calculations

- 2019 and 2023 masses share similar trend
  - 2023 shown here
- **CMM diameter with 2023 caliper heights result in least spread of densities**
  - Marginal improvement over nominal (or drawing) diameters with 2023 caliper heights

| Diameter Measured | Height Measured | Average Density | Variance | Standard Deviation |
|---|---|---|---|---|
| Nominal | Nominal | 18.36 | 0.07 | 0.27 |
| Nominal | 2023 Caliper | 18.56 | 0.03 | 0.16 |
| Nominal | 2019 Caliper | 18.38 | 0.08 | 0.28 |
| 2023 CMM | 2023 CMM | 16.97 | 0.77 | 0.88 |
| 2023 CMM | 2023 Caliper | 18.57 | 0.02 | 0.16 |
| 2023 CMM | 2019 Caliper | 18.39 | 0.07 | 0.27 |

# Conclusions

- CMM measurements of 38 plates took around one week
  - Confirmed nominal diameters are correct
- CMM measured **stack** heights should be used when possible
  - Highly consistent values
  - Allows for indirect measurement of gaps
- 2023 CMM measured diameter paired with 2023 caliper heights and masses result in the densities with the smallest spread
- Nominal diameter paired with 2023 caliper heights and masses are only slightly worse
- Recommendation:
  - Use of CMM diameters or nominal diameters both yield consistent results

# References


1. Intl. Handbook of Evaluated Criticality Safety Benchmark Experiments (2023).
2. J. HOOGTERP, “Request for Oy (93%),” , memo: N-2-871.
3. Thompson, N., Sanchez, R., Goda, J., Amundson, K., Culter, T., Grove, T., Hayes, D., Hutchinson, J., Kostelac, C., McKenzie, G., McSpaden, A., Myers, W., Walker, J., et al. A New Era of Nuclear Criticality Experiments: The First 10 Years of Comet Operations at NCERC. Nucl. Sci. Eng. 2021, vol 195, No. SUP1, pp. S17-S36
4. J. GODA, “HEU Data Jemima Plates 2019,” , LA-UR-19-24229 (2019).
5. INSPIRE, [software program]. Hexagon. https://hexagon.com/products/inspire.

# Acknowledgments

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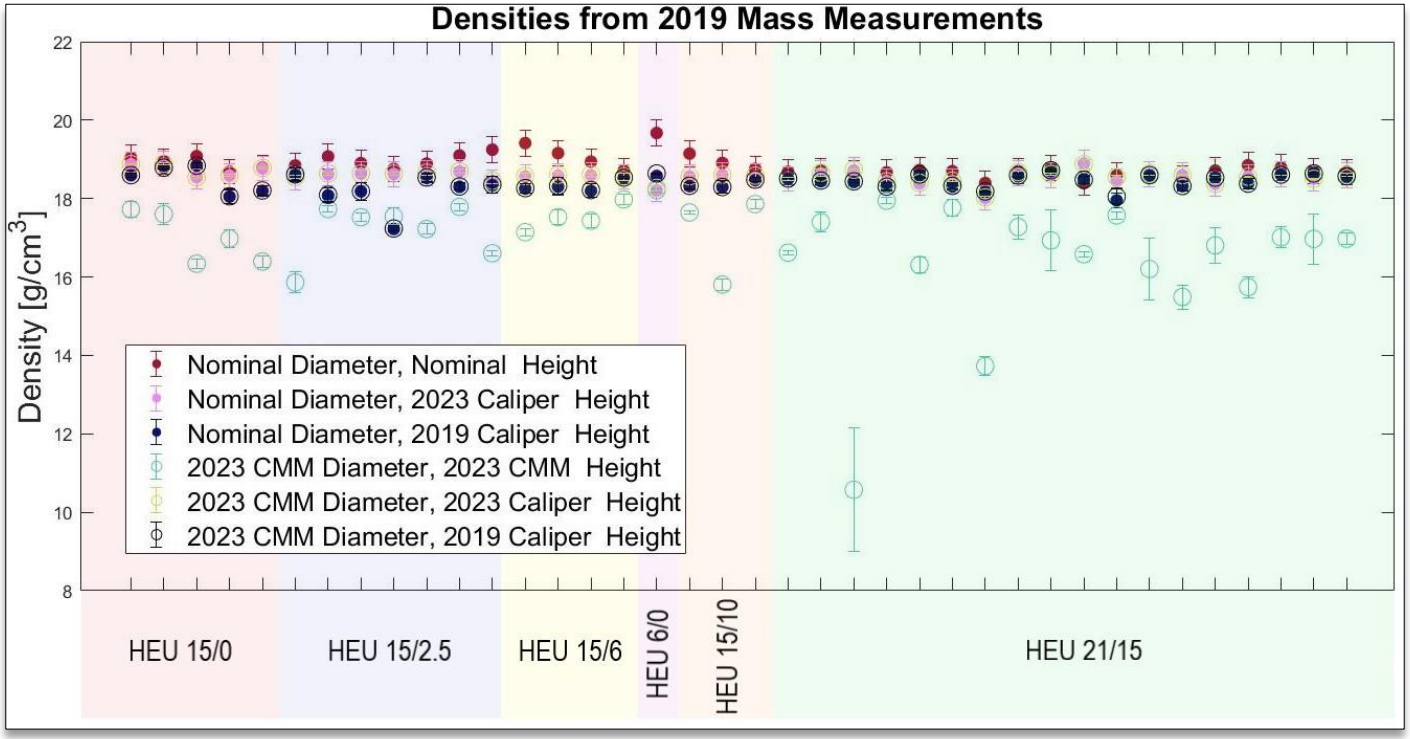
Questions?

# Extra Slides

Statistical variance and standard deviation of densities calculated with the 2019 masses.

| Diameter Measured | Height Measured | Average Density | Variance | Standard Deviation |
|---|---|---|---|---|
| Nominal | Nominal | 18.37 | 0.07 | 0.27 |
| Nominal | 2023 Caliper | 18.61 | 0.03 | 0.18 |
| Nominal | 2019 Caliper | 18.39 | 0.08 | 0.28 |
| 2023 CMM | 2023 CMM | 16.98 | 0.77 | 0.88 |
| 2023 CMM | 2023 Caliper | 18.58 | 0.02 | 0.16 |
| 2023 CMM | 2019 Caliper | 18.40 | 0.07 | 0.27 |


Densities from 2019 Mass Measurements
Density [g/cm$^3$]
22
20
18
16
14
12
10
8
Nominal Diameter, Nominal Height
Nominal Diameter, 2023 Caliper Height
Nominal Diameter, 2019 Caliper Height
2023 CMM Diameter, 2023 CMM Height
2023 CMM Diameter, 2023 Caliper Height
2023 CMM Diameter, 2019 Caliper Height
HEU 15/0
HEU 15/2.5
HEU 15/6
HEU 6/0
HEU 15/10
HEU 21/15